BURNER CONTROL SENSOR CONFIGURATION

RELATED APPLICATION

[0001] The present application is related to and claims priority of U.S. Provisional Application Serial No. 60/524,986 filed November 25, 2003.

FIELD OF INVENTION

[0002] The field of invention pertains to combustion detection within a burner or tail gas combustor that is part of a fuel processing system comprising a fuel reformer and a fuel cell.

BACKGROUND

[0003] Hydrogen, which is used in fuel cells, is most commonly created by steam reforming. The steam reforming reaction in a fuel processing system is endothermic, meaning heat is absorbed by the reaction. Therefore, heat needs to be supplied to the system to drive the reaction. In "pure" steam reforming, heat is supplied from an outside source to a catalyst bed. In "partial oxidation" and "autothermal reforming," heat is created within the catalyst bed by oxidation of some fuel with air.

[0004] The need to transport heat from an outside source to a catalyst bed can be an obstacle to rapid startup or rapid change of operating parameters in a steam reformer. This can be avoided by using autothermal reforming. In autothermal reforming, fuel, steam and also a controlled amount of air are mixed and injected into the reactor. The oxygen in the air then reacts with some of the fuel, usually in the presence of a catalyst, thereby producing heat. The heat is absorbed by the reforming reaction, as described above, which is occurring at the same time in the same catalyst bed. Once the system is at operating temperature, the amount of heat required can be generated in a controlled way by controlling the ratio of the inlet air to the amount of fuel being reformed. Likewise, in steam reforming the amount of external heating by a burner or other heat source may be varied.

[0005] However, fuel processing systems usually must be initially heated so that the catalyst reaches an effective operating temperature. Preheating by hot gas, or electricity, or by pre-combustion or local ignition is required to start up a cold steam reformer or ATR reactor. While this is not difficult in a large, fixed chemical plant, it is more demanding in a mobile reformer, for example in a vehicle, or in a small reformer at a non-industrial site,

such as in a distributed electric power generating system. Such small reformers may need to undergo frequent cold startup.

[0006] A key problem is how to start the reforming reaction in the first place. Clearly heat must be supplied from some other source, such as combustion external to or within the reforming bed, or via electrical heating of the catalyst, to raise the temperature enough to start the autothermal reforming or steam reforming reactions. When combustion is used to supply heat, the combustion reaction typically occurs in a burner. In a burner, air and fuel are mixed and burned to generate heat and the heat is used to heat up a reformer, for example, to bring the catalyst to the operation temperature, and/or to continually supply heat to sustain the reforming reaction.

[0007] For example, when the reformer is a "pure" steam reformer, a dedicated burner is used to supply the heat required for reforming. Such burners typically start up using a spark to ignite a flame. The flame heats a catalytic combustor up to operating temperature, and subsequently catalytic combustion may occur on the combustion catalyst in the burner. The heat released in the burner is used to heat up the steam reforming catalyst to its operating temperature. Once the stream reforming starts, the burner continues to run to supply heat to sustain the endothermic steam reforming reaction.

[0008] In an autothermal reformer (ATR), an auxiliary burner may be used at startup to supply heat to bring ATR catalyst to a predetermined operating temperature. The auxiliary burner likewise starts up with a spark and flame. The hot combustion gas then heats up the catalyst in the burner until the temperature of the catalyst reaches a point that catalytic oxidation of the fuel occurs on the surface of the catalyst, which is referred to as the flameless catalytic combustion. Moreover, in an integrated fuel reformer/fuel cell system (a "fuel processor"), hydrogen or reformate that is not consumed in the fuel cell is consumed in the same burner or in a different auxiliary burner, sometimes called a tail gas combustor or TGC. The heat so generated may be used to assist in reforming fuel, or used for other purposes such as space heating.

[0009] When a combustion source is to be used in a home or a building, "proof of lean combustion" is required by certification ~~agencies~~ for combustion equipment. Historically, proof of combustion has been provided by supplying a suitable detector for an open flame, such as an ionization type detector. However, in a fuel processor, it can be difficult to establish combustion by such a simple method because, as described above, the point of combustion and/or the type of combustion may change during operation. In particular,

during startup the combustion may change from a flame driven by a spark, to a flameless oxidation on the combustion catalyst.

[0010] Lean combustion is also desirable, and generally required, for safety reasons as well as for regulatory purposes. Lean combustion means that more than stoichiometric amount of air is present in the combustion reaction, i.e., a fuel/air stoichiometry of less than 1. "Fuel" may include hydrocarbon fuels such as hydrocarbons (e.g., natural gas and gasoline) as well as alcohols, and unreacted hydrogen, such as those in anode exhaust gas from the fuel cell. If combustion is incomplete due to lack of sufficient air, undesirable byproducts such as carbon monoxide may be formed and unreacted fuel may be present. These are considered safety and environmental hazards. Furthermore, incomplete combustion lowers the system efficiency since all the fuel is not reacted. Accordingly, lean combustion is preferred to operate efficiently, since if incomplete combustion takes place fuel is wasted.

[0011] Described below is an innovative way to evidence lean combustion in a fuel reformer or fuel processor. The method uses a flame detector, one or more temperature sensing devices, and optionally an oxygen or hydrocarbon sensor, to provide signals to a controller that can be used to monitor and control combustion.

SUMMARY OF THE INVENTION

[0012] The present invention is generally directed to a method for verifying combustion in a burner of a fuel reformer during warm up and steady operation comprising first detecting for flame within a burner of a fuel reformer during an initial warm-up stage of operation of a fuel reformer, then proceeding with operation of the fuel reformer if a flame is detected within the burner. The operation of the reformer can be discretionally continued or halted absent the positive detection of a flame in the burner. Further, the method may include monitoring a temperature of a catalyst within the burner to determine the occurrence of flameless catalytic combustion, then proceeding with operation of the fuel reformer if a predetermined temperature is achieved by the catalyst within the burner. The predetermined temperature of the catalyst within the burner is preferably above the temperature at which the catalyst operates as a flameless oxidation catalyst. Again, the operation of the reformer may be discretionally continued or halted absent the achievement of the predetermined temperature. Finally, the method comprises detecting for flame within

the burner to indicate continued combustion during subsequent stages of operation of the reformer, and then producing a burner exhaust.

[0013] The method may further comprise the step of determining the completeness of combustion after producing a burner exhaust. In one embodiment of the invention, determining the completeness of combustion comprises sensing for oxygen in the burner exhaust to produce a reading, wherein a positive reading for oxygen indicates complete combustion. Alternatively, in another embodiment, determining the completeness of combustion comprises sensing for hydrocarbon fuel in the burner exhaust to produce a reading, wherein a negative reading for hydrocarbon fuel indicates complete combustion.

[0014] It is also an aspect of an embodiment of the invention that the step of monitoring a temperature comprises providing at least two temperature sensors within the burner, and comparing an output of each temperature sensor. If the difference between any two outputs of different sensors exceeds a predetermined value, then a "system error" is registered.

[0015] In another embodiment of the invention, a burner input can be controlled based on the completeness of combustion. Control of burner input can alternatively be based on the reading for oxygen in the burner exhaust or on the reading for hydrocarbon fuel in the burner exhaust.

[0016] In still another embodiment of the invention, the method for verifying combustion in a burner of a fuel reformer during warm up and in steady operation comprises the steps of providing at least one flame detector to detect combustion during an initial warm up stage, providing at least one temperature-sensing device to monitor a temperature of a burner catalyst to evidence that the catalyst reaches a predetermined temperature, thereby indicating flameless catalytic combustion, and then providing a system controller to select a flame detection device to validate combustion at each stage of operation.

[0017] An embodiment of this method may further comprise the step of providing at least one of either an oxygen sensor and a hydrocarbon sensor monitoring a burner exhaust to demonstrate lean combustion. Again, the method may control burner input based on a reading from the at least one of either an oxygen senor and a hydrocarbon sensor monitoring the burner exhaust.

[0018] In still another embodiment, the present invention may be used for proving lean combustion in a catalytic burner associated with a fuel reformer. The method may include the steps of providing at least one flame detector capable of sensing the presence a flame, and providing at least one temperature sensor capable of determining a temperature of a

catalyst in the catalytic burner. In an embodiment of this method, the at least one flame detector verifies combustion when the catalyst in the burner is below a predetermined operating temperature, and the at least one temperature sensor verifies combustion when the catalyst temperature is above a predetermined operating temperature. A response in the temperature of the catalyst due to a variation in a supply of air is used to verify lean operation of burner.

[0019] With respect to the apparatus of the present invention used to practice the various embodiments of the disclosed methods, generally a burner assembly associated with a fuel reformer designed to combust fuel in a manner in which combustion of the fuel can be verified is disclosed. The burner assembly preferably comprises an outer shell housing a combustion chamber comprising a burner, a catalyst bed situated within the combustion chamber, a mixing zone in fluid communication with the combustion chamber, an air inlet and a fuel inlet in communication with the mixing zone, wherein a supply of air through the air inlet and a supply of fuel through the fuel inlet are mixed within the mixing zone, an exhaust outlet in fluid communication with the combustion chamber, wherein an exhaust stream is discharged from the combustion chamber through the exhaust outlet, a flame detector positioned such that it is capable of detecting the existence of flame in the combustion chamber, a temperature sensor positioned such that it is capable of monitoring temperature of the catalyst bed, and an exhaust detector positioned downstream of the catalyst bed and capable of detecting at least one of either oxygen or hydrocarbon in the exhaust stream.

[0020] In an additional embodiment, the burner assembly may further comprise a controller for controlling at least one of either the supply of fuel and the supply of air admitted to the mixing zone.

[0021] In still another embodiment of the burner assembly, lean combustion of the fuel can be verified comprising an outer shell housing a combustion chamber comprising a burner and a catalyst bed, a mixing zone in fluid communication with the combustion chamber, an air inlet and a fuel inlet for directing a supply of air and fuel, respectively, into the mixing zone, an exhaust outlet for discharging exhaust from the combustion chamber, a flame detector comprising a window for detecting flame in the chamber, a temperature sensor for sensing a temperature of the catalyst bed, and a controller programmed to verify, after initial warm-up, lean combustion by varying the input of at least one of either a supply

of air and a supply of fuel and determining if the temperature in at least one of either the combustion chamber and the catalyst bed respond in an expected manner.

[0022] These an other embodiments of the method and apparatus of the present invention will be understood from the following description in conjunction with the drawing figures appended hereto.

FIGURES

[0023] Figure 1 is a schematic illustration of one embodiment of the present invention.

[0024] Figure 2 is a schematic illustration of another embodiment of the present invention.

DESCRIPTION OF THE INVENTION

[0025] In this application, the term "burner" and the phrase "tail gas combustor" are used interchangeably to describe a vessel where the combustion of fuel and air takes place to generate heat. The term "fuel" includes any hydrocarbon, alcohol, reformate stream , unreacted hydrogen from a fuel cell stack, and reformate from a fuel cell stack. "Air" includes any oxygen containing gas suitable for use in a burner. Likewise, "hydrogen" includes any hydrogen containing gas suitable for use in a burner, and in particular pure hydrogen and reformate. "Reformer" includes any catalytic vessel responsible for the production of hydrogen by a steam reforming reaction.

[0026] The present invention describes methods and apparatus for demonstrating proof of combustion within a burner or tail gas combustor of a fuel processing system in a fuel cell power plant. This process may be generally referred to in the following description as verifying (-ication), validating, demonstrating, proving, and evidencing combustion within a burner. Such references are used interchangeably without distinction. However, a distinction is made herein as to verifying combustion and verifying lean combustion---the latter being a subset of the former.

[0027] The disclosed methods and apparatus may comprise the use of flame detection devices, one or more temperature sensing devices, and an oxygen or hydrocarbon fuel-sensing device to produce an output demonstrating combustion, and more particularly, in certain embodiments, demonstrating lean combustion.

Flame Detectors

[0028] The flame-detecting device shows proof of flame, i.e. that the air and fuel have been ignited within the burner. Any type of flame detector is potentially suitable for use in the present invention. Commonly used types of flame detectors that may be used for proof of combustion include, without limitation, flame ionization detectors (FID), particularly ionization /rectification flame detectors; and light-based flame detectors, including ultraviolet light detectors, photoelectric eyes (visible light detectors), and infrared detectors.

[0029] An ionization/rectification flame detector (FID), often referred to as a flame rod, is a well known device and is preferred. Ions are released in an intermediate phase of combustion. In a typical FID, two electrodes are placed within the flame. A potential difference is placed across the electrodes, which produces an electric current between the electrodes when an ionizing flame is present.

[0030] In a FID, it is possible to form a carbon bridge between the two electrodes which conducts a current and causes a false positive detection of flame. To avoid this, it is common practice for one electrode to have a greater surface area than the other electrode, and the potential difference across them is alternated. The resulting current will be rectified if conducted by ions produced in a flame and not rectified if conducted by a carbon bridge.

[0031] Ultraviolet (UV) light detectors, infrared (IR) light detectors, and photoelectric (visible) eyes may also serve the same function as the FID, i.e., to prove whether or not there is a flame. Each of these type of detectors uses a window to select the wavelength of a light emitting from a flame. The light then falls on a detector such as a photodiode or other electronic detection device. If the intensity of light exceeds a threshold, the presence of flame is validated.

Temperature Sensors

[0032] Once the combustion catalyst in a catalytic burner is at its operation temperature, catalytic oxidation may occur on the catalyst surface. The catalytic oxidation usually does not have a visible flame and therefore a flame detector may not be effective in this operation mode. Instead, temperature sensors may be used to monitor the catalyst temperature and ensure that combustion continues. Such monitoring may be a perceptible display of a temperature, or merely a simple signal to indicate achievement of a threshold temperature.

[0033] In one embodiment, the temperature sensing devices are used to prove combustion by verifying that the temperature of the burner catalyst exceeds the auto combustion temperature of the fuel being placed in the burner catalyst bed. Two or more

temperature sensing devices are often used to monitor combustion in various locations in the burner. The types of temperature sensing devices which may be used in this invention include, without limitation, any conventional device capable of detecting and reporting high temperatures, for example in the range of about 200 to about 700 deg. C. Many such devices are known in the art; examples include type K thermocouples, type N thermocouples, thermistors, resistive temperature devices, thermometers, and infrared detectors. Type K thermocouples are presently preferred.

Oxygen/Fuel Sensors

[0034] A flame detector combined with at least one temperature sensor may verify combustion. However, this combination of elements may not be able to differentiate between a lean and a rich combustion mixture. Accordingly, an additional sensor may be needed to determine completeness of combustion.

[0035] In a specific embodiment, an oxygen sensor for detecting oxygen levels in the burner exhaust is used. The results from the oxygen sensor, in way of a reading, display, perceptible signal, or the like, may be used to determine whether or not complete combustion has taken place. To ensure lean combustion, a burner controller monitors the mixture of the flame with the oxygen sensor. For example, if the oxygen sensor detects oxygen in the combustion exhaust, it typically indicates complete combustion (i.e., a rich combustion mixture). However, if oxygen is not detected in the exhaust, this may be indicative of incomplete combustion. In that case, the oxygen sensor could send a signal and the burner controller could close off the fuel supply for the burner. Also, the oxygen sensor may indicate whether or not combustion has taken place, since the level of oxygen in the flow is decreased by combustion. That is, if the oxygen level in the exhaust shows a decrease when measured against the oxygen input to the system, combustion within the system can be presumed.

[0036] While a variety of oxygen sensor types are available, a preferred type for the present embodiments is an automotive-type oxygen sensor. Other oxygen sensor types may also find suitable uses with alternative embodiments.

[0037] Instead of or in addition to the oxygen sensor, a hydrocarbon or fuel sensor may also be used to verify combustion, operating in a similar fashion to the oxygen sensor. If, after combustion, the hydrocarbon sensor detects the presence of hydrocarbons, this will indicate that combustion is incomplete. However, if the hydrocarbon sensor fails to detect any hydrocarbons, this may verify that complete combustion has taken place.

[0038] In a current embodiment, an oxygen sensor is used to verify that combustion is complete. The oxygen sensor may be preferred in some cases because it is lower in cost and more durable than current hydrocarbon detectors.

[0039] Since a small or trace amount of oxygen or hydrocarbon may exist even in the case of complete combustion, the intensity of signals which triggers controller actions shall be determined experimentally, as described later in the specification.

[0040] Finally, it is preferable to test the sensor or sensors periodically during operation to ascertain signal validity. For temperature measurement, the preferred method, in one embodiment, is to provide two or more temperature sensors, preferably three or more, and to compare their signal levels by digital or analog methods. In addition, the reading can be compared under "cold" conditions to maintain calibration. For an oxygen sensor, the signal obtained under cold conditions (i.e., the air is, or can be arranged to be, at atmospheric levels) can be compared with preset values. It is also possible to validate the oxygen sensor by starting the flame under known rich conditions, and increasing air flow to known lean conditions and observing the sensor output. Other strategies are also possible.

[0041] Figures 1 and 2 show two embodiments of the present invention. In Figure 1, a combination of an ionization/rectification flame detector and thermocouples is used to show proof of combustion, and an oxygen sensor is used to demonstrate leanness of the combustion. The burner/tail gas combustor, shown generally at 10, has inlets for air 12 and fuel 13 which are mixed in a mixing zone 14. At startup, the fuel/air mixture from mixer 14 is ignited by ignitor 15 (for example, a spark plug) and enters through an opening in the burner wall 16 of a chamber 17. The flame 18 created by the spark is initially found in chamber 17. A flame ionization detector 19 detects ions from the flame 18. The hot exhaust gas from the flame 18 then enter a catalyst bed 20. As the catalyst warms up, its temperature is monitored by thermocouples 21, type K in the present embodiment. Two thermocouples 21 are illustrated, but three or more may actually be used. The burner wall 16 is typically grounded by a ground connection 22 to improve sensor stability. After passing through catalyst bed 20, the combusted gases enter an exhaust 23. There, the oxygen concentration would be detected by oxygen sensor 24. If complete combustion has taken place, the oxygen sensor 24 will detect excess oxygen. If a hydrocarbon or hydrogen detector were used, it could also be located at or near the exit; it would signal lean combustion by failing to detect hydrocarbons.

[0042] Figure 2 is essentially identical to Figure 1 except that the FID is replaced by a transparent window 25 behind which is a photodetector 26 — these devices may physically be combined in a single device. As noted above, the window 25 is typically transparent in a selected wavelength range, most typically in the ultraviolet and/or visible range, but may also or instead be in the near infrared range.

[0043] In operation, the igniter 15 and the detectors 19 or 26, 21 and 24 are connected to a microprocessor or other controller (not shown), which controls the burner during startup, steady operation, and shutdown. The controller can also shut off the supplies of air 12 and fuel 13. The decision routines are programmed into the controller by standard procedures. At startup, the controller admits air and fuel into the mixer 14, and the igniter 15 is energized. If a flame 18 is not detected by flame detector 19 or photocell 26 within a set period, the system can be shut down. If a flame 18 is detected, then the controller monitors the oxygen detector 24 and the thermocouples 21. The controller expects to see a reduction in oxygen concentration (below atmospheric) after ignition. A zero reading from the oxygen sensor 24 is permissible shortly after ignition, but after a set time the oxygen sensor 24 is expected to read above a certain level to prove that the combustion is lean. If the criterion is not met, the system can be shutdown by the controller.

[0044] The controller is then capable of monitoring the rate of increase of the temperature in the catalyst bed 20 by reading the output from the thermocouples 21. The temperature may be required to reach a preset level within a fixed time. Failure to achieve this requirement might indicate that a problem exists and the system could be shut down. In normal operation, the catalyst bed would reach a temperature known to be sufficient for flameless combustion of the fuel/air mixture ("light-off" temperature). When this temperature has been exceeded by a predetermined minimum amount for a set time, the controller would preferably deactivate the igniter 15 and, optionally, the flame detector 19 or 26. If a reading of the oxygen sensor 24 did not change within certain limits, and provided the temperature of the catalyst bed 20 stays above a critical temperature, then the system could continue to operate in a steady-state mode. The controller can be optionally programmed to perform tests periodically during prolonged operation to validate readings of the various sensors, particularly the thermocouples 21 and the oxygen sensor 24. One method of achieving this might be to slightly change the air/fuel ratio and observe expected changes in the bed temperature and in the oxygen concentration in the exhaust.

[0045] Shut-down can be very simple; for example, the fuel supply could be turned off, and after a sufficient degree of cooling the air supply could also be turned off. The shutdown process provides another opportunity to calibrate the sensors.

[0046] The above description of certain embodiments is intended to enable a skilled person to understand the invention, as set forth in the appended claims. The limits of the invention are found in the claims.